SUSY 2002

DESY Hamburg, 17-23 June 2002

GMSB searches at LEP




Outline

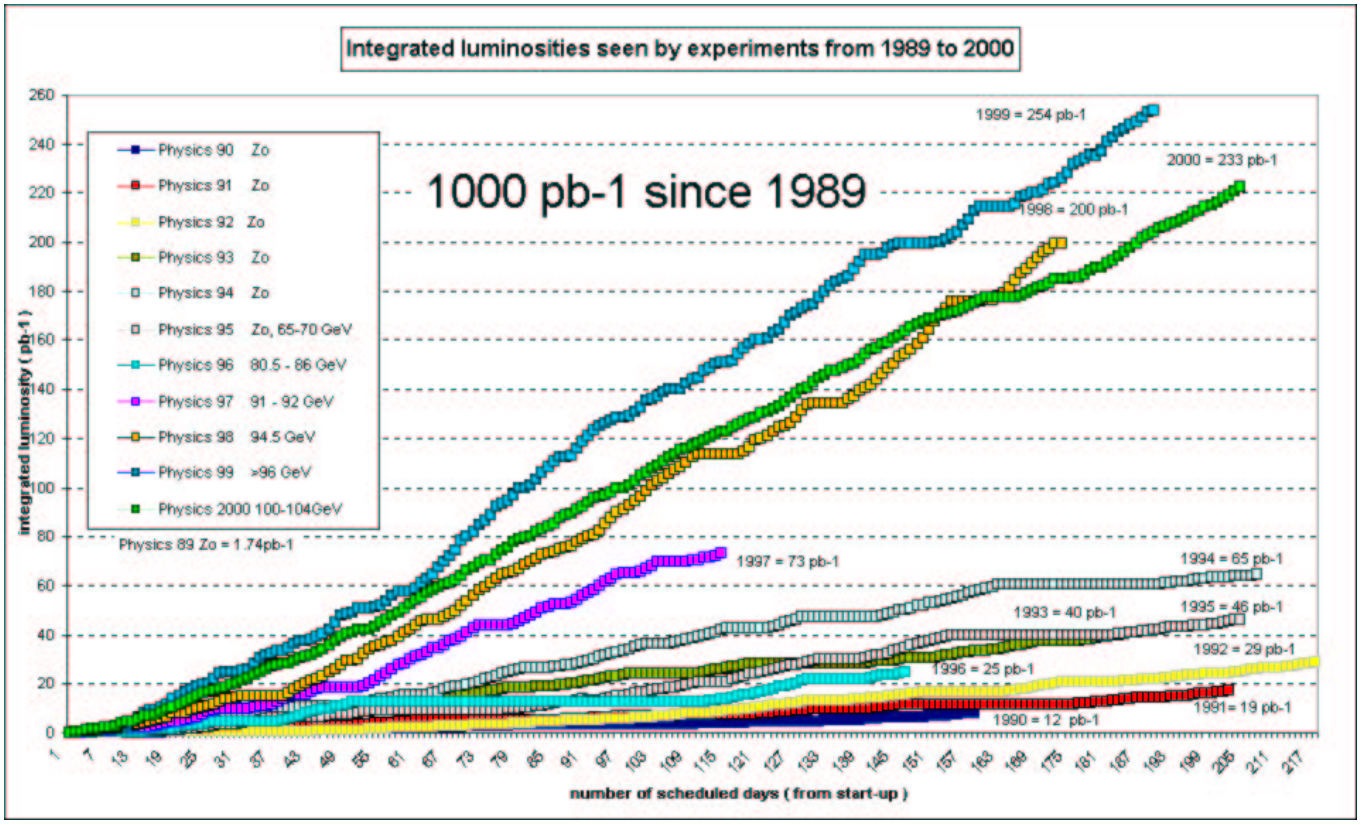
- GMSB phenomenology
- Searches and combined results for:
  - ★ neutralino NLSP
  - ★ slepton NLSP
- Interpretation
- Conclusions

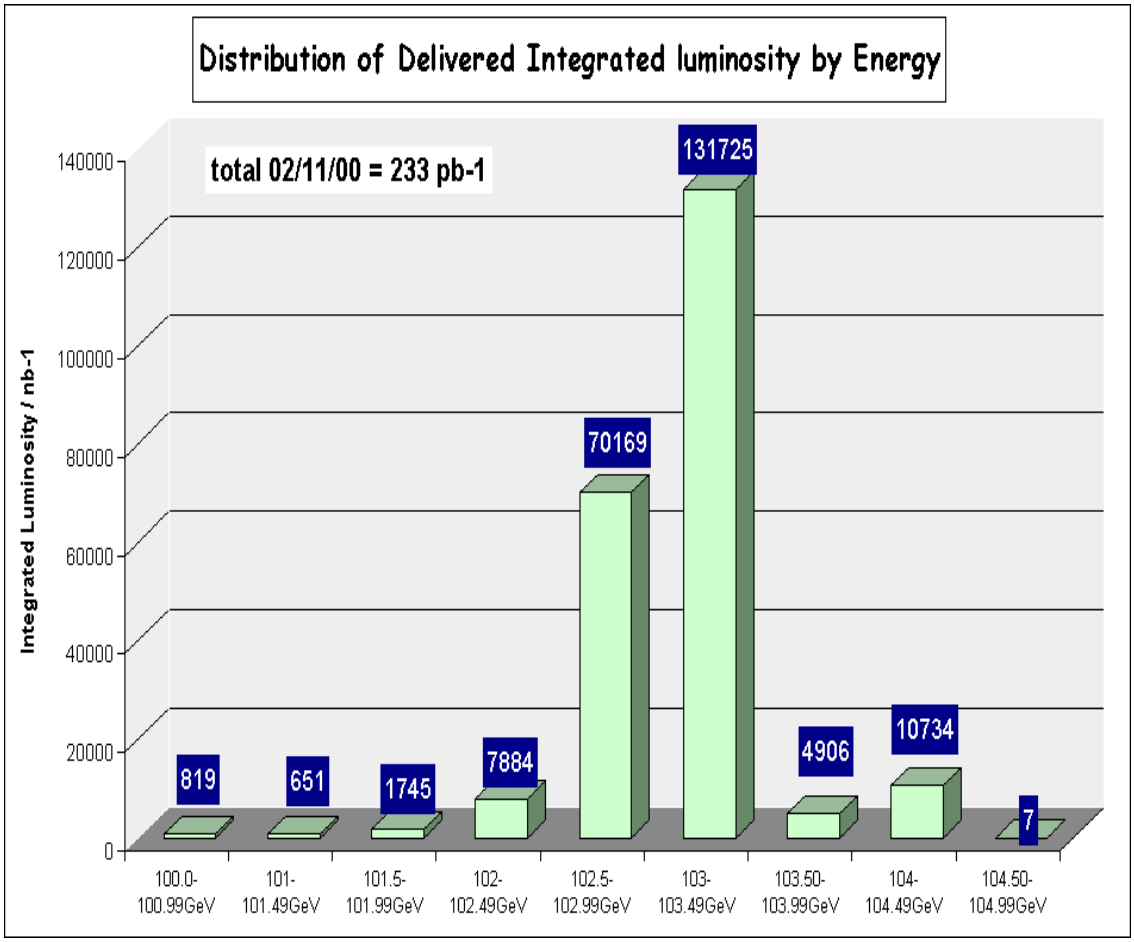
Arán García-Bellido

Royal Holloway
University of London

http://www.pp.rhul.ac.uk/∼garcia/pubs/lepgmsb02.ps.gz

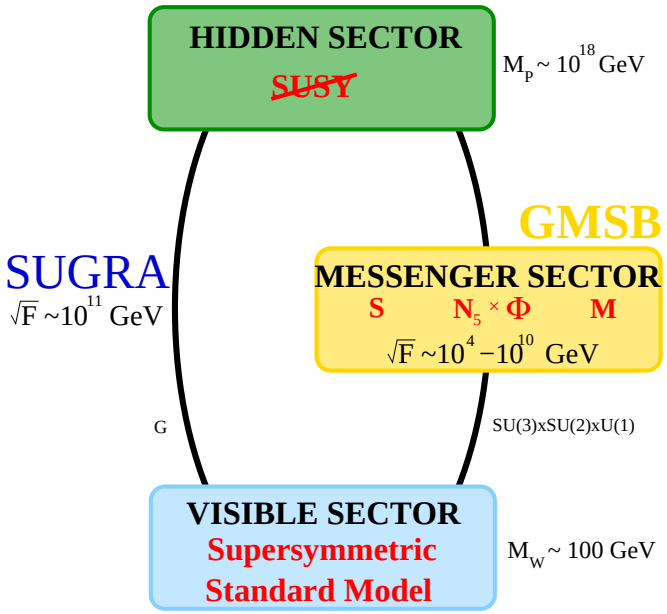
The LEP Dataset





Thanks LEP!

Mediation of SUSY breaking



SUSY breaking can be communicated down to the visible sector via:

Gravity	Gauge interactions
FCNC?	no FCNC: low energy + flavour blind
$m_{\tilde{G}} \simeq 2.4 \left(\frac{\sqrt{F}}{100\ \text{TeV}} \right)^2$ eV	
$m_{\tilde{G}} \sim$few TeV	$10^{-2} < m_{\tilde{G}} < 10^4$ eV
$\tilde{\chi}_1^0$ LSP	$\tilde{G}$ LSP

Gauge Mediated SUSY Breaking

Six parameters to define minimal GMSB models:

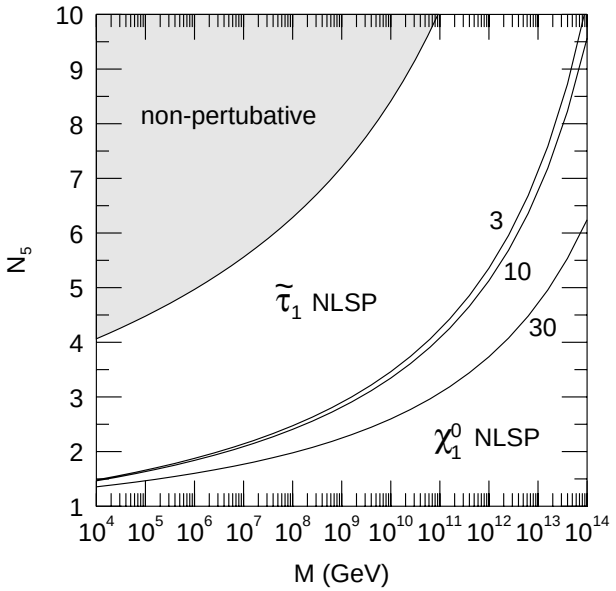
$\sqrt{F}$	SUSY breaking scale in the messenger sector
N_5	number of messenger pairs
M_{mess}	messenger mass scale
Λ	universal mass scale of SUSY particles
$\tan\beta$	ratio of Higgs vacuum expectation values
$sign(\mu)$	sign of Higgs sector mixing parameter

GMSB phenomenology

- $\tilde{G}$ is the LSP:
  10^{-2} eV $\lesssim m_{\tilde{G}} \lesssim 3$ keV
-

$$NLSP = \begin{cases} \tilde{\chi}_1^0 \rightarrow \gamma\tilde{G} \\ \tilde{\ell} \rightarrow \ell\tilde{G} \end{cases}$$

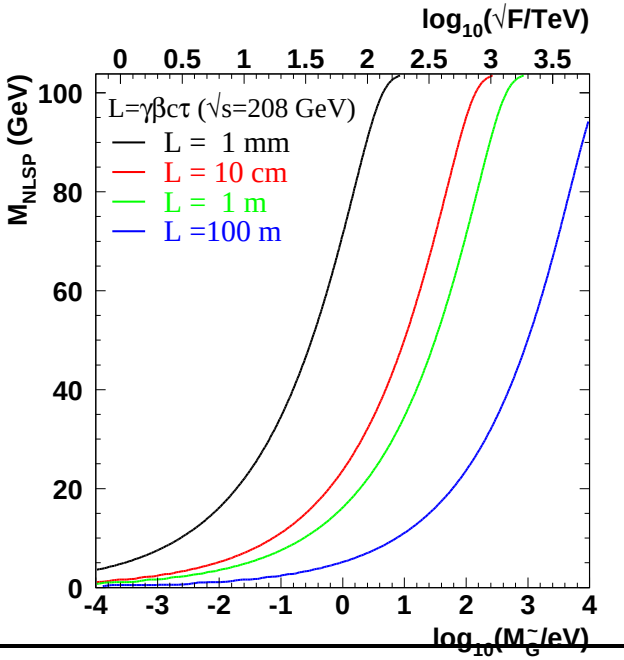
- $\tilde{\tau}_R$ and $\tilde{\tau}_L$ mix $\Longrightarrow$ $\tilde{\tau}_1$ NLSP
  (large $\tan\beta$)



- Decay length of the NLSP:

$$c\tau \approx \frac{0.01}{\kappa_\gamma}\left(\frac{100\ \text{GeV}}{m_{\text{NLSP}}}\right)^5\left(\frac{m_{\tilde{G}}}{2.4\ \text{eV}}\right)^2 \text{cm}$$

(κ_γ=1 for $\tilde{\ell}$ NLSP)



Signatures depend on the NLSP type and NLSP decay length

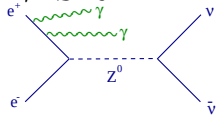
↓

Many different topologies!

$\tilde{\chi}$ NLSP

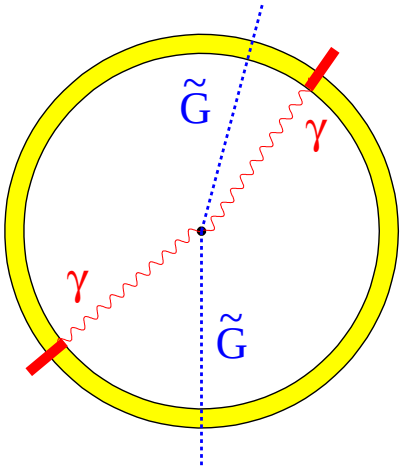
Short $\tilde{\chi}$ lifetime: $c\tau < 1$ cm ➡ **Two acoplanar γ**

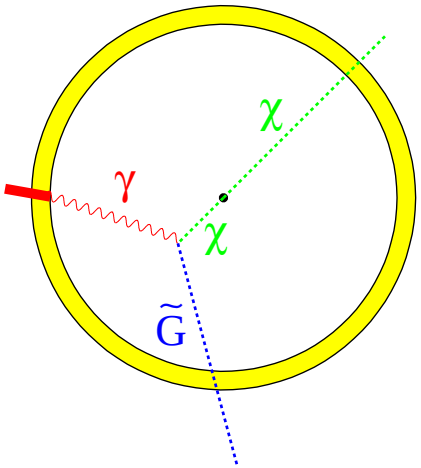
- Also $e^+e^- \to \tilde{\chi}_1^0\tilde{G} \to \gamma\tilde{G}\tilde{G}$ and $e^+e^- \to \tilde{G}\tilde{G}\gamma_{ISR} \Leftrightarrow M_{\tilde{G}} \sim 10^{-4}$ eV
- Suffer irreducible bkg: $e^+e^- \to \nu\bar{\nu}\gamma(\gamma)$

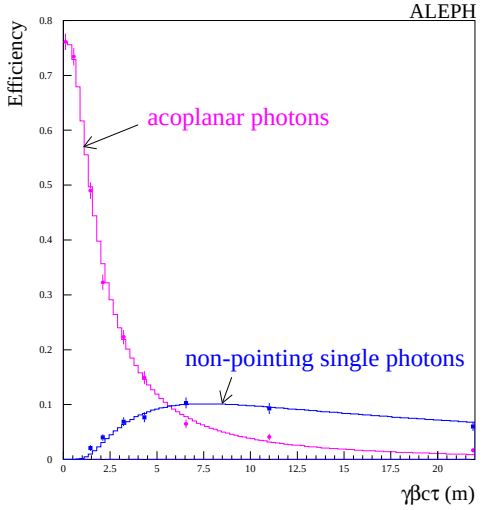


Medium $\tilde{\chi}$ lifetime: $c\tau \sim \ell_{\text{detector}}$ ➡ **Non pointing γ(s)**

- Require impact parameter > 40 cm
- Impact parameter reconstructed from the EM shower axis
- Bkg: $\nu\bar{\nu}\gamma(\gamma)$ + cosmic rays → bremsstrahlung from out-of-time muons





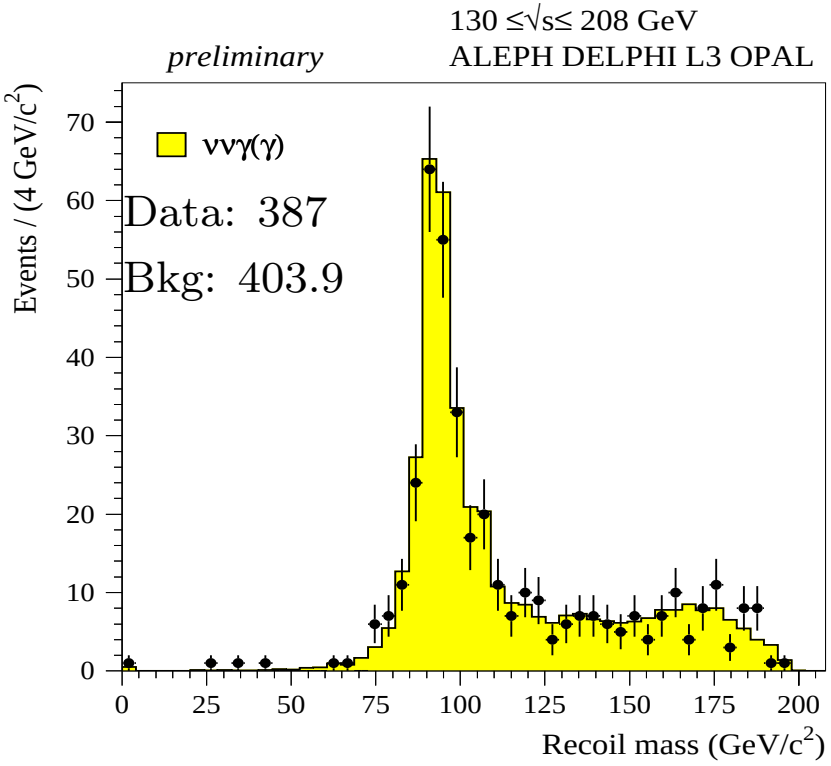


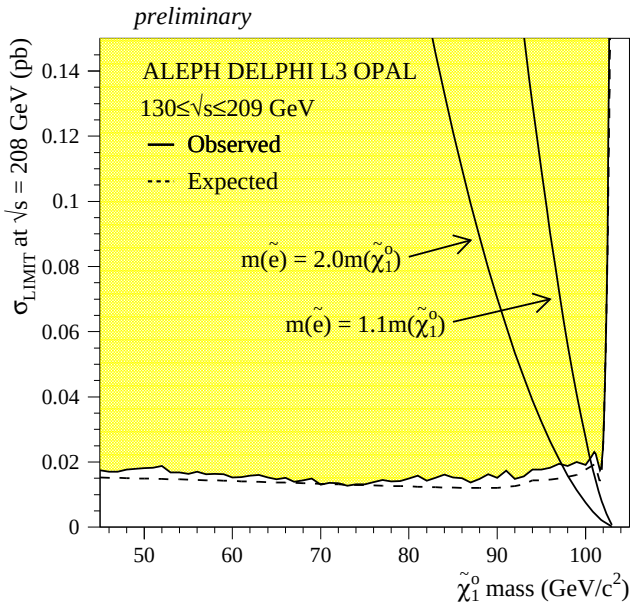
☞ If $c\tau > \ell_{\text{detector}}$: Indirect limits from 'standard' $\tilde{\ell}$ and $\tilde{\chi}^{\pm}$ searches

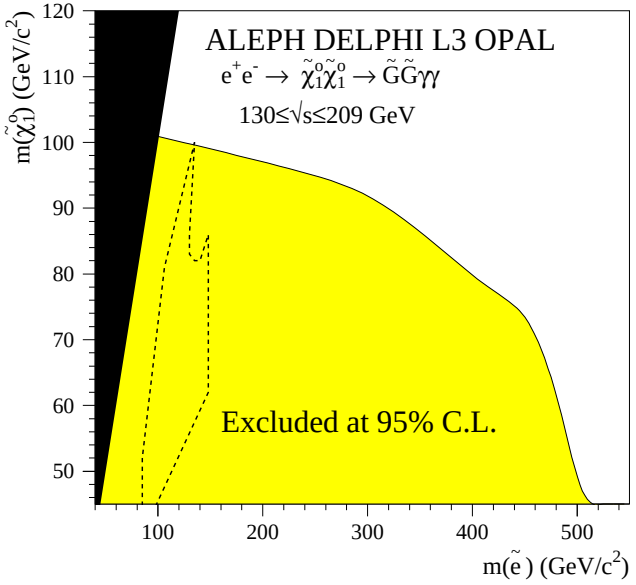
$\tilde{\chi}$ NLSP: No lifetime

Topology: two acoplanar photons pointing to the vertex and $\not{E}$

- Look for two high energy photons and $\not{p}_t$
- Use as discriminant: recoil mass against the photon system
- CDF event $2e+2\gamma+\not{E}$ ruled out



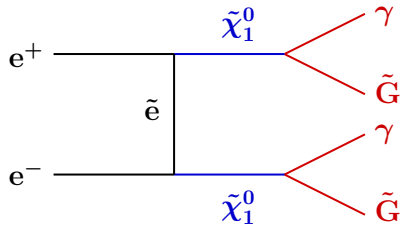




$\mathbf{m_{\tilde{\chi}_1^0} > 97\,GeV/c^2}$ for $m_{\tilde{e}_R} = 2 \times m_{\tilde{\chi}_1^0}$

$\tilde{\chi}$ NLSP: Medium lifetime

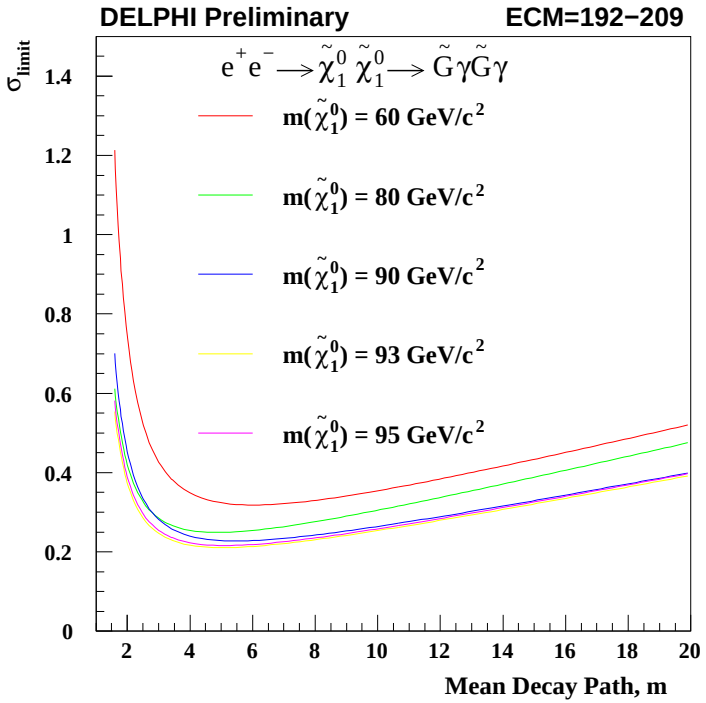
Topology: Non pointing photon(s)
(unlikely that both χ decay inside the detector)

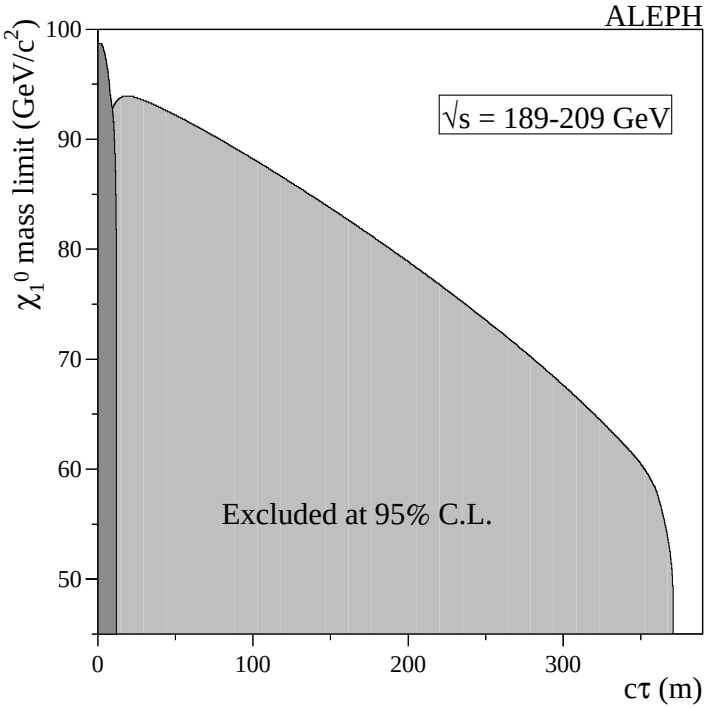


- Reconstruct impact parameter from EM shower axis ($d_0 > 40$ cm)
- Good agreement in total number of events:

ALEPH (189-209 GeV):	2 obs./1.0 exp.
DELPHI(130-209 GeV):	16 obs./14.6 exp.

($m_{\tilde{e}_R} = 1.1\ m_\chi$ and χ is bino)





$\tilde{\ell}$ NLSP

Short $\tilde{\ell}$ lifetime: $c\tau < 1$ cm ➡ **2 acoplanar $\ell + \not{E}$**

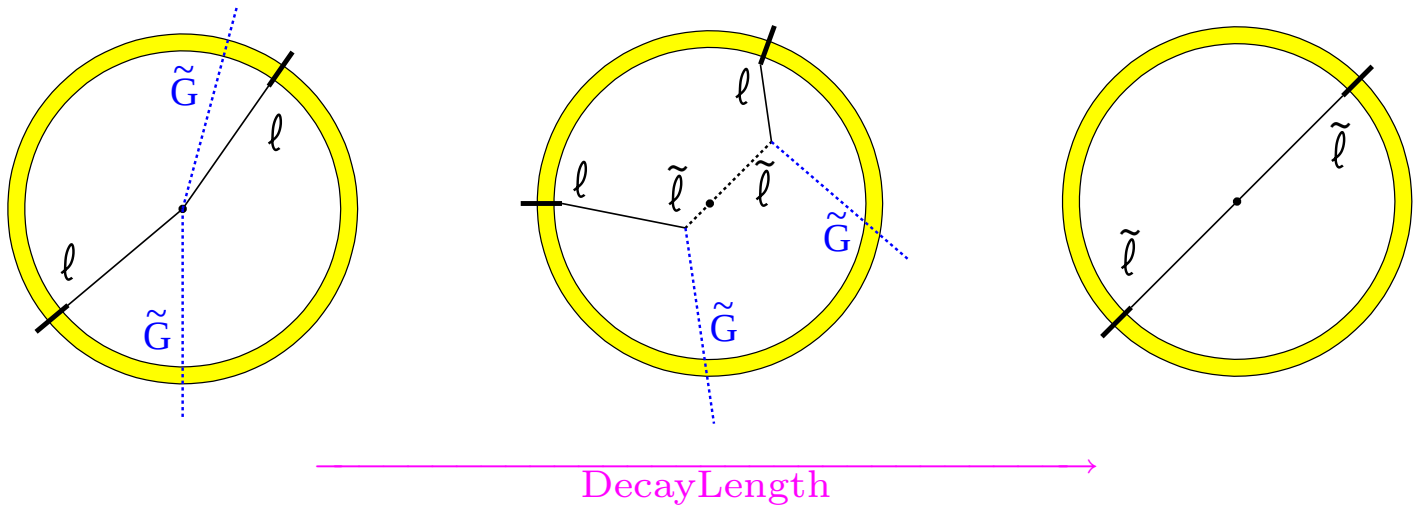
- Major bkg.: WW production, $\gamma\gamma$ processes

Medium $\tilde{\ell}$ lifetime: $c\tau \sim \ell_{\text{detector}}$ ➡ **kinks + large IP**

- Look for large Impact Parameter tracks ($1 \lesssim L \lesssim 40$ cm) and kinked tracks ($10 \lesssim L \lesssim 200$ cm)
- Major bkg.: cosmic rays, $\gamma\gamma$ and decays of K^0_s (large IP) and $K^{\pm}$ (kinks)

Long $\tilde{\ell}$ lifetime: $c\tau > \ell_{\text{detector}}$ ➡ **Heavy Stable Ch. part.**

- Two back to back particles: highly ionising tracks



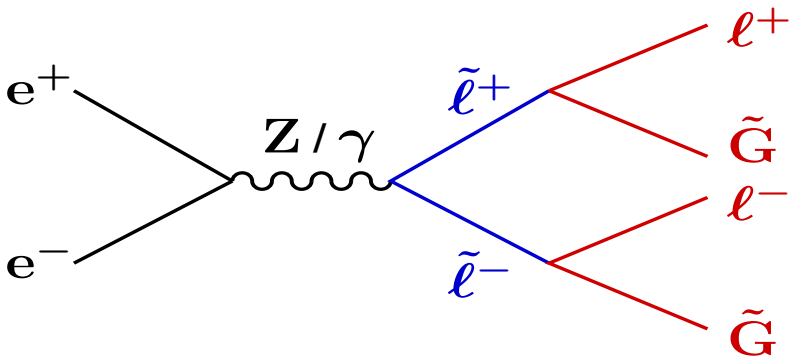
$\tilde{\ell}$ NLSP: Prompt decay

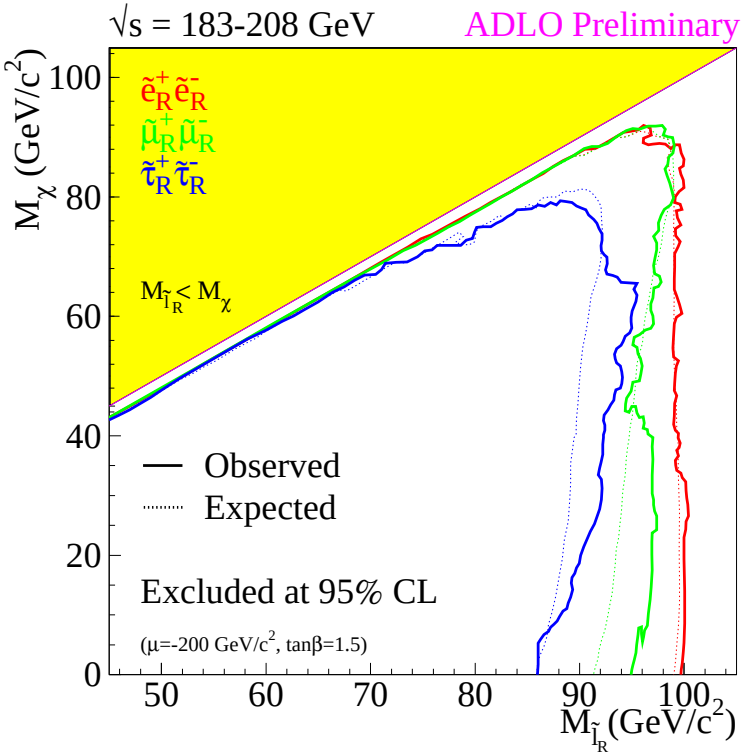
Topology: $e^+e^- \rightarrow \tilde{\ell}^+_R\tilde{\ell}^-_R \rightarrow \ell^+\ell^- \tilde{G}\tilde{G}$ (acoplanar leptons)

- Identical to $\tilde{\ell}^+_R\tilde{\ell}^-_R \rightarrow \ell^+\ell^- \tilde{\chi}^0_1\tilde{\chi}^0_1$ with $m_{\tilde{\chi}^0_1} \sim 0$ in SUGRA
- Search for two identified leptons and $\not{E}$
- No excess seen ... $\Longrightarrow$ set limits:

ADLO lower limits @ $m_\chi = 0$

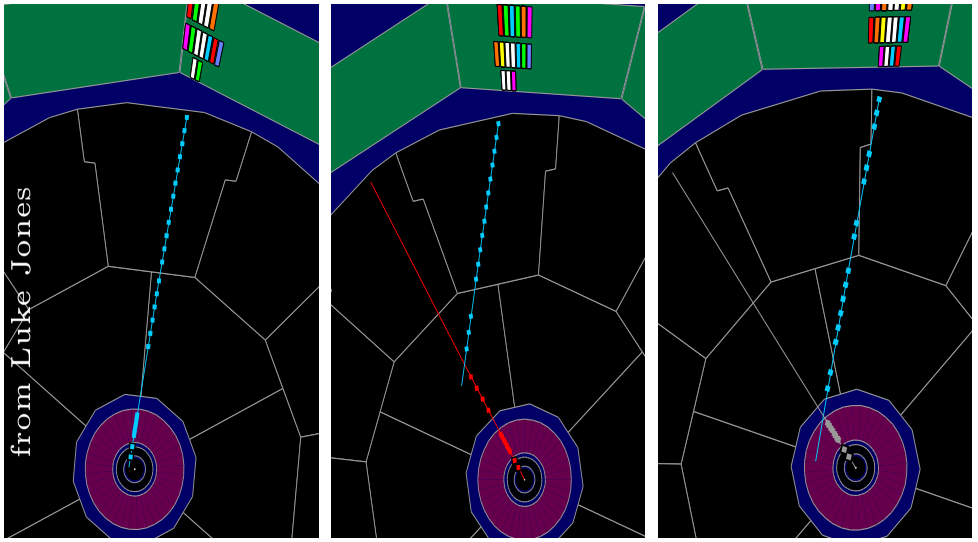
	$m_{\tilde{e}}$	$m_{\tilde{\mu}}$	$m_{\tilde{\tau}}$
obs	99.6	94.9	85.9
exp	99.2	91.4	85.8



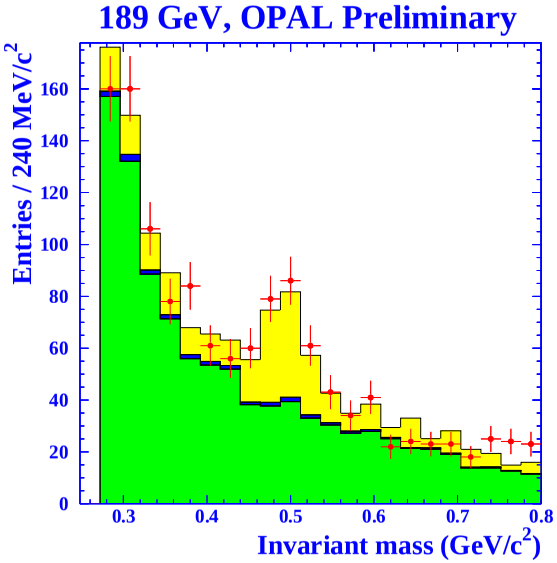


$\tilde{\ell}$ NLSP: Medium lifetime

- Slepton decays before reaching tracking devices $\longrightarrow$ large IP
  - ★ Require at least one (non-tau) track with $|d_0| > 1$ cm
- Slepton decays in the tracking chamber $\longrightarrow$ kinked track
  - ★ Use kink angle and energy veto to discern from hard bremsstrahlung and hadronic interactions: $\pi^{\pm} \to \mu^{\pm}\nu$, $K^{\pm} \to \mu^{\pm}\nu$ or $\pi^{\pm}\pi^0$



large IP | TPC kink | ITC kink



K^0_S peak of sec. tracks

ALEPH	DELPHI	OPAL
1 obs./1.1 exp.	9 obs./7.4 exp.	1 obs./1.1 exp.($\tilde{e}, \tilde{\mu}$)
		7 obs./4.4 exp.($\tilde{\tau}$)

$\tilde{\ell}$ NLSP: Long lifetime

Topology: Heavy Stable Charged particles

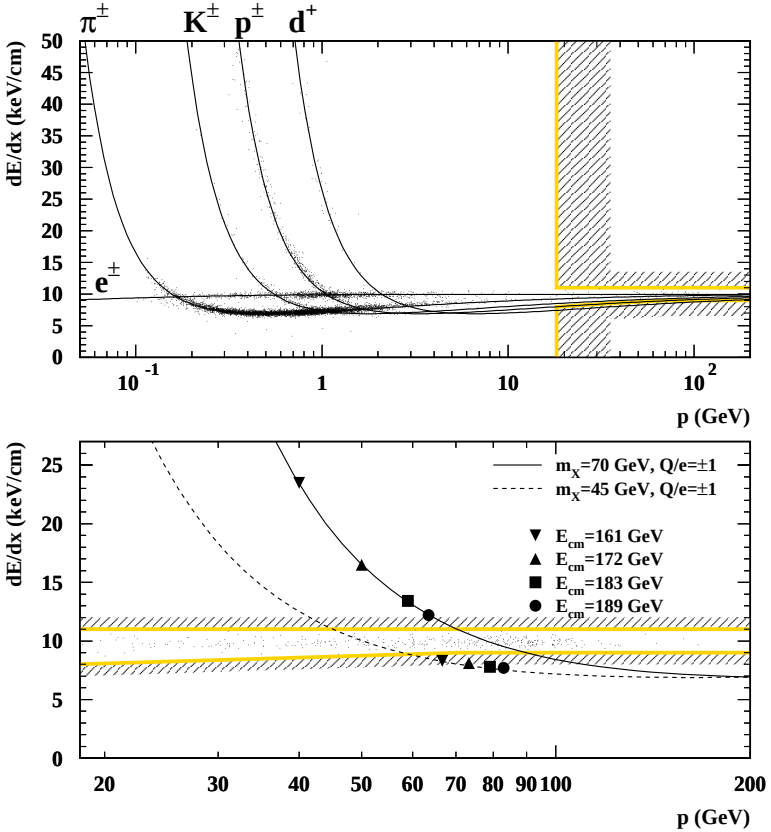
- Look for two back–to–back tracks
- with anomalous high or low dE/dx
- High efficiency ($\sim 90\%$) & very low SM bkg

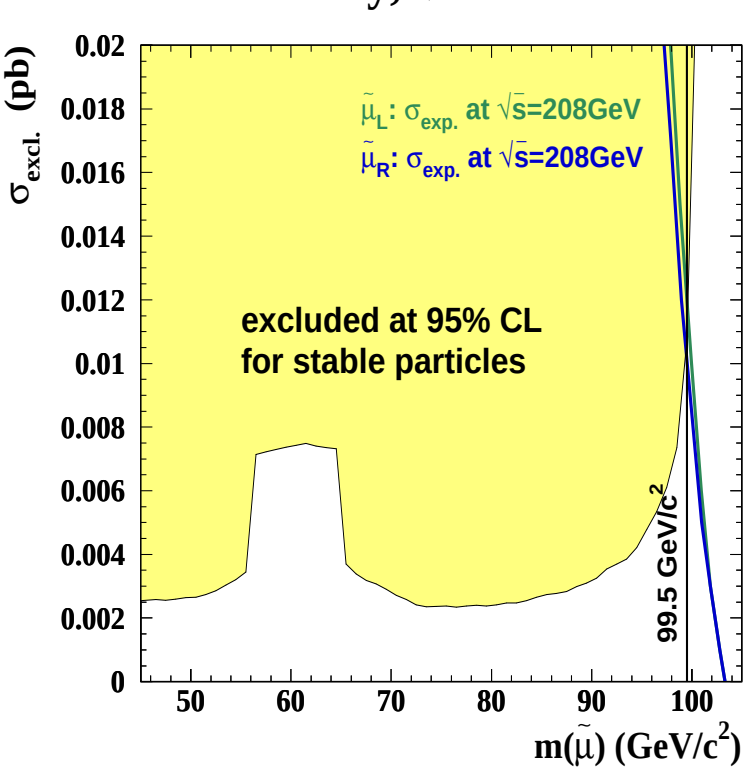
$\sqrt{s} = 189 - 209\,\mathrm{GeV}$

ALEPH: 1 obs./2.3 exp.

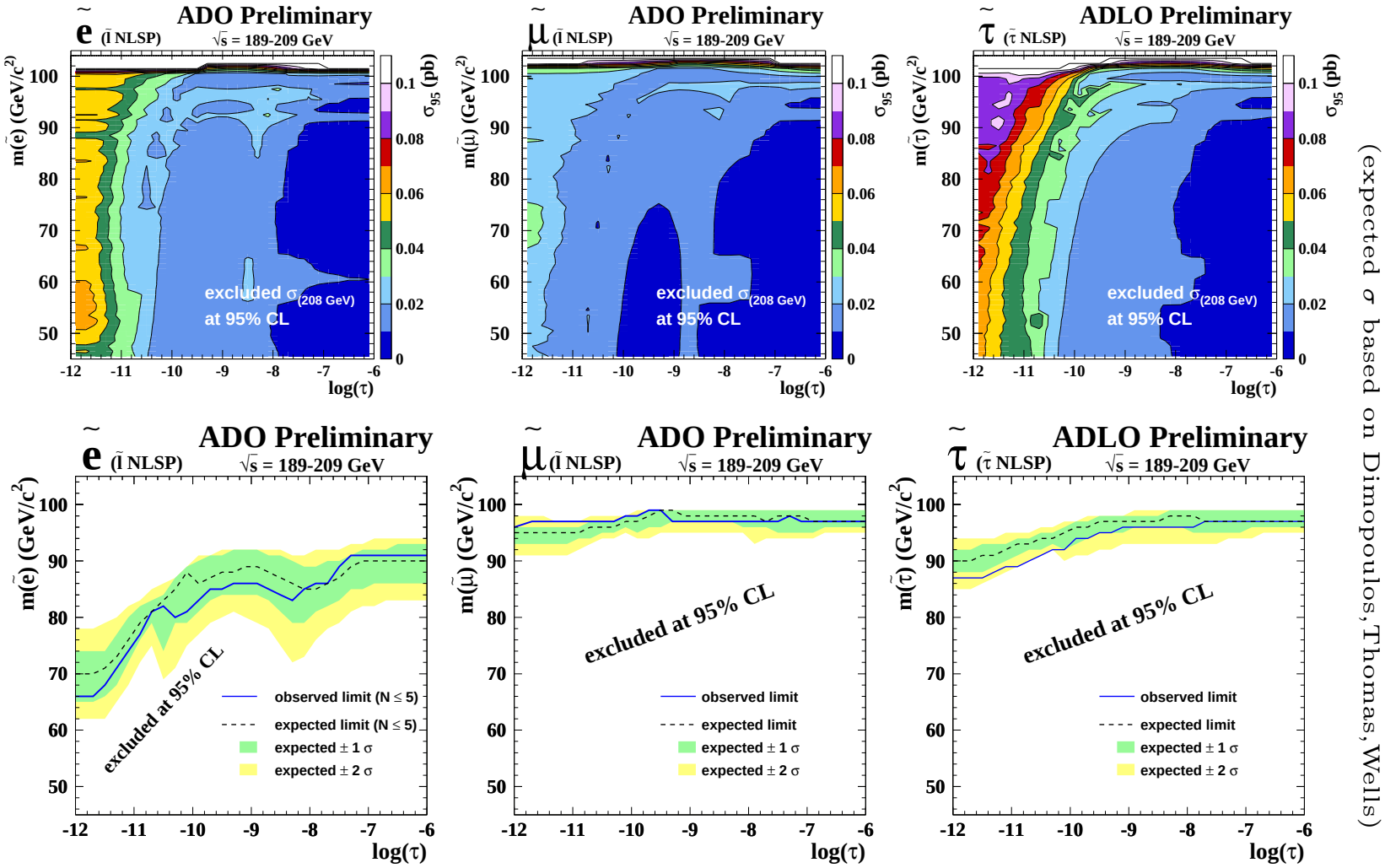
DELPHI: 1 obs./2.7 exp.

OPAL: 1 obs./0.6 exp.





Slepton mass combined limits



(expected σ based on Dimopoulos, Thomas, Wells)

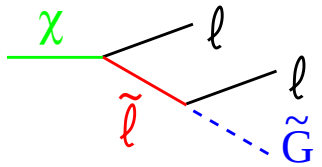
ADO ADO ADLO

$m_{\tilde{e}} > 65.8\,\mathrm{GeV}/c^2$ $m_{\tilde{\mu}} > 96.3\,\mathrm{GeV}/c^2$ $m_{\tilde{\tau}} > 86.9\,\mathrm{GeV}/c^2$

(limits at 95% CL, valid for all lifetimes and $N_5 \leq 5$)

$\tilde{\ell}$ NLSP: Cascade decays

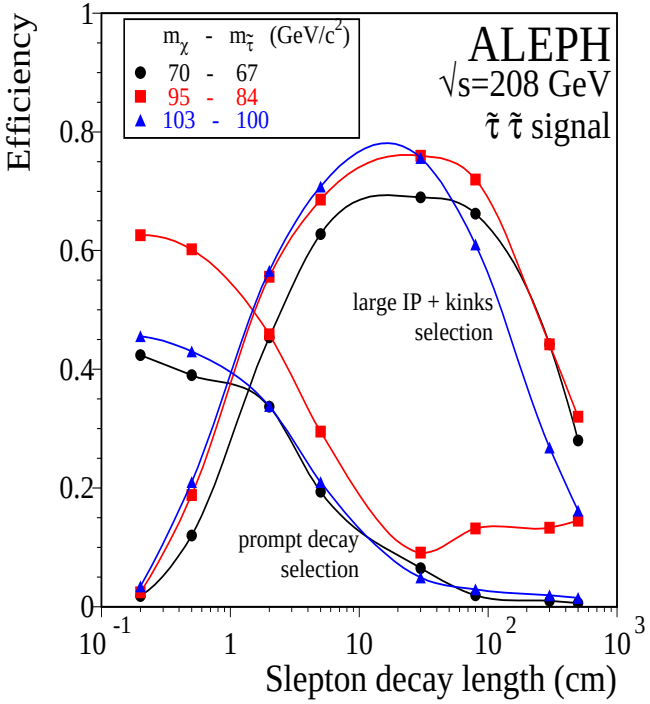
Study $e^+e^- \rightarrow \chi\chi$ with

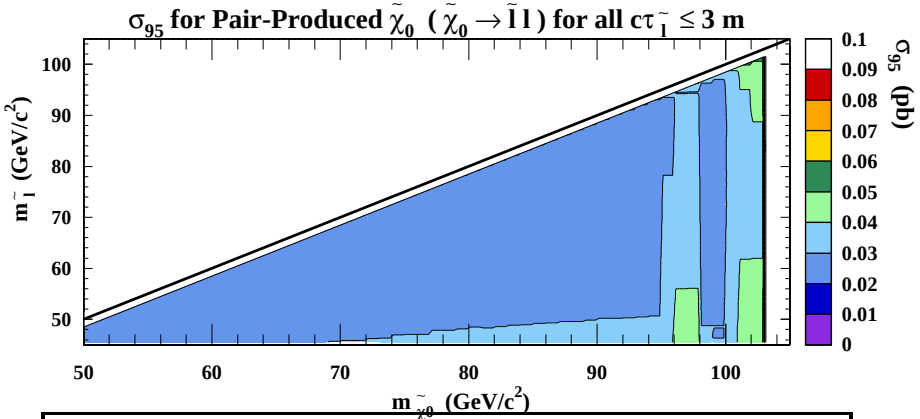


to benefit from larger ($\times$ 2) cross section

Topology: Final state with 4 lepton/tau + $\not\!\!E$

- Search for two energetic and two soft ℓ
  - ★ also new searches with lifetime: kinks or large IP
- χs decay independently $\rightarrow$ six selections: $\tilde{e}\tilde{e}$, $\tilde{\mu}\tilde{\mu}$, $\tilde{\tau}\tilde{\tau}$, $\tilde{e}\tilde{\mu}$, $\tilde{e}\tilde{\tau}$, $\tilde{\mu}\tilde{\tau}$
  - ★ Strong dependence on $\Delta M = m_\chi - m_{\tilde{\ell}}$
- No excess $\Rightarrow$ 95% C.L. limits on production cross section:





$\tilde{\tau}\tilde{\tau}$ selection, $\sqrt{s}$=189-209 GeV	
$4\ell + \not\!\!E$:	large d_0 and kinks:
A: 22 obs./16.5 exp.	A: 5 obs./5.3 exp.
D: 15 obs./11.6 exp.	0: 5 obs./5.4 exp.
O: 5 obs./5.0 exp.	

Other possibilities (DO)

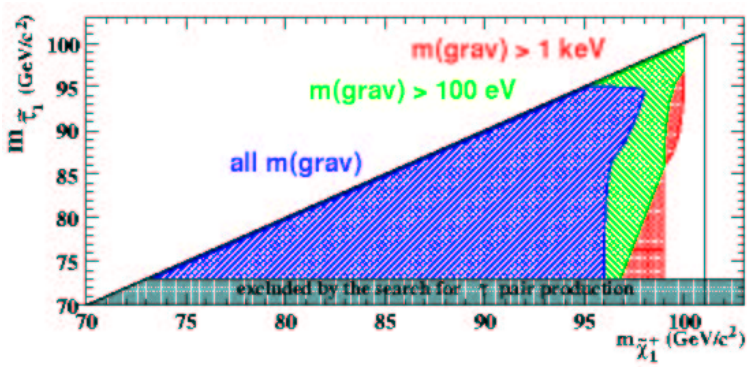
Charginos with $\tilde{\ell}$ NLSP: $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\ell}^+\tilde{\ell}^-\nu\bar{\nu} \to \ell^+\ell^-\tilde{G}\tilde{G}\nu\bar{\nu}$

- Look for $2\,\ell + \not{E}$ like in SUGRA. Different kinematics in lifetime case
- $m_{\tilde{\chi}_1^\pm} > 95.2$ GeV/c^2 at 95% C.L. for $\Delta M \geq 0.3$ GeV/c^2

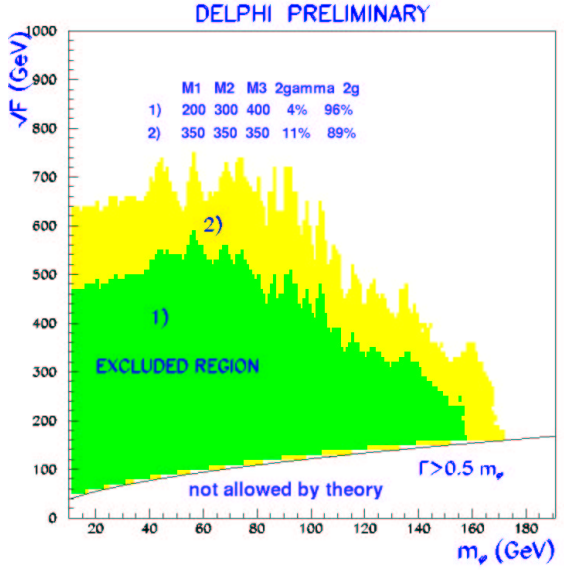
Sgoldstinos $e^+e^- \to S\gamma \to \begin{matrix}\gamma\gamma\gamma \\ gg\gamma\end{matrix}$

- For ultralight $\tilde{G}$ ($\Leftrightarrow$ $\sqrt{F}$ very small) $\to$ $\tilde{G}$ is mainly goldstino
- Search for its heavy SUSY partner: Sgoldstino S (+ monochr. γ)
- Not seen $\Rightarrow$ exclude $\sqrt{F} - m_S$ plane for different gaugino mass values

DELPHI $\sqrt{s}$=189-202



DELPHI $\sqrt{s}$=189-208



GMSB Interpretation

Perform scan over parameter space, eg:

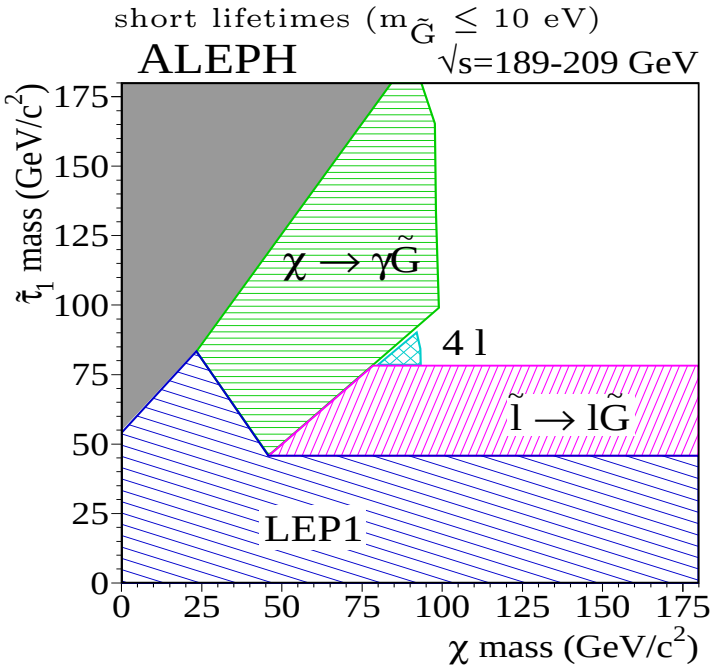
Combine:

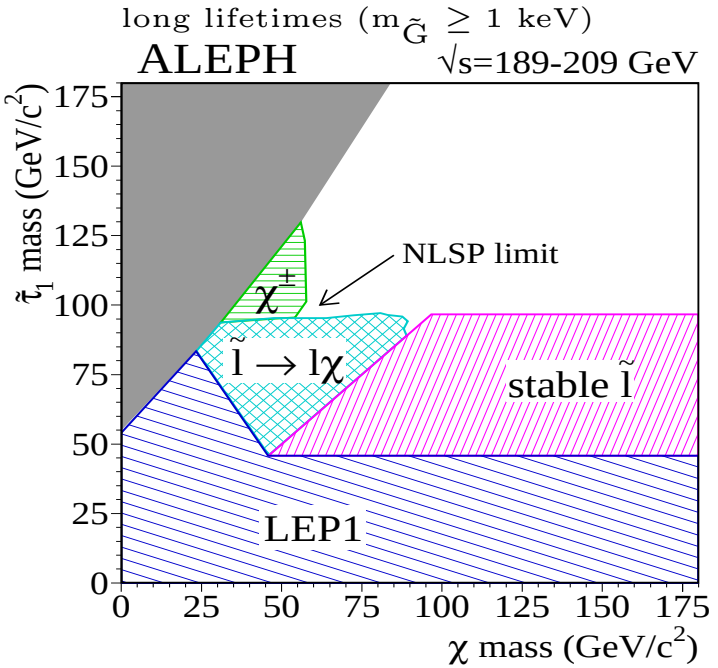
- ★ all topologies and all lifetimes
- ★ LEP1 exclusion
- ★ MSSM $\tilde{\ell}$ & $\tilde{\chi}^{\pm}$ limits
- ★ Higgs limits from $(m_h, \sin^2(\beta-\alpha))$

$$10^4 \leq M_{\rm mess} \leq 10^{12} \text{ GeV}$$
$$0.1 \leq m_{\tilde{G}} \leq 10^5 \text{ eV}$$
$$1 < \Lambda < \min(\sqrt{F}, M) \text{ TeV}$$
$$1.5 \leq \tan\beta \leq 40$$
$$1 \leq N_5 \leq 5$$
$$\text{sign}(\mu) = \pm 1$$

Absolute (indirect) lower mass limit on the NLSP:

$M_{NLSP} > 54$ **GeV**/c^2 (independent of lifetime)





GMSB Interpretation

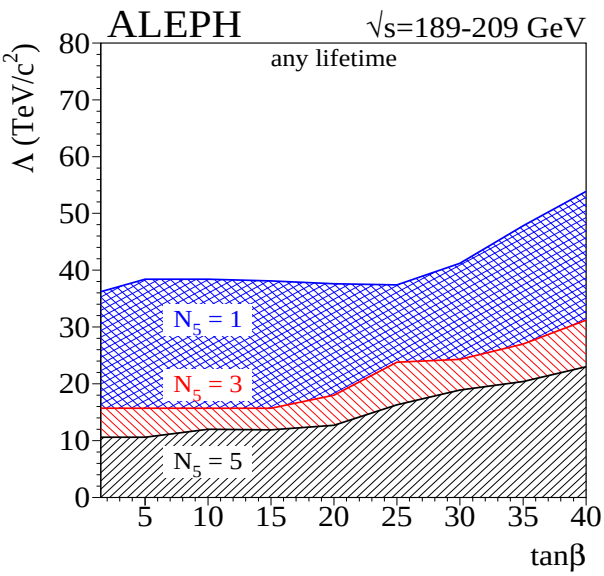
Gaugino and sfermion masses depend on Λ and N_5

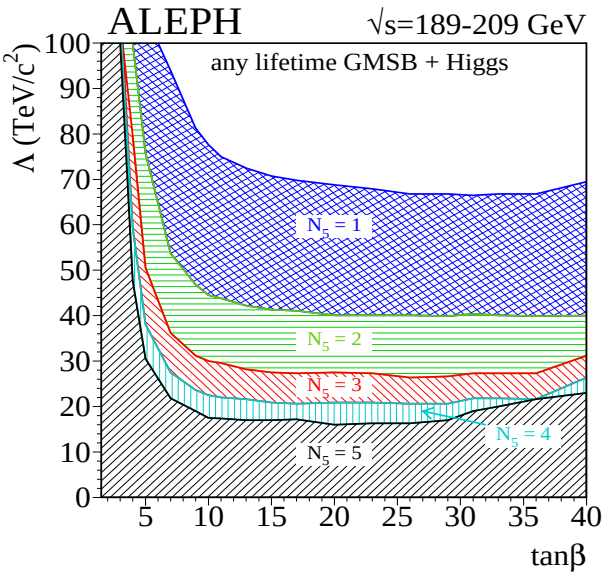
$M_\lambda \propto N_5\Lambda$

$M^2_{\tilde{f}} \propto N_5\Lambda^2$

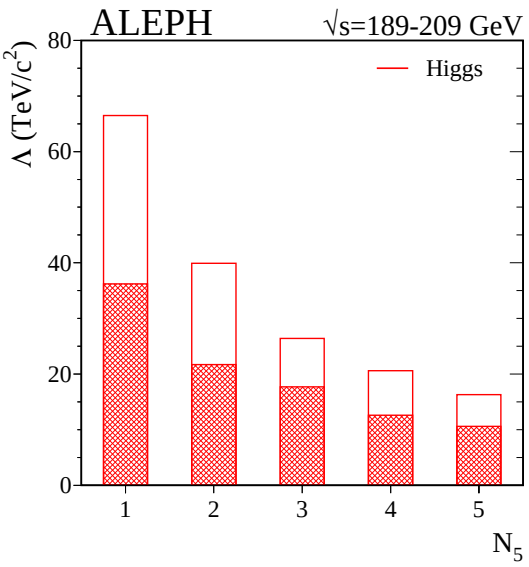
→ Λ controls the mass scale of SUSY particles

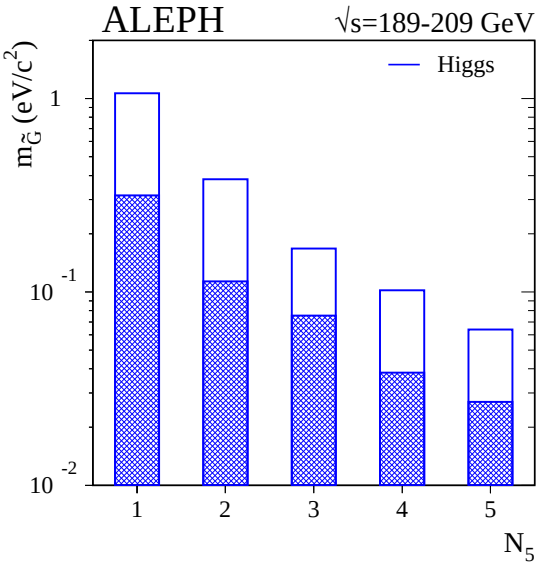
Set an absolute limit on Λ:





$\Lambda > 10\ (16)\ \mathrm{TeV}/c^2$





Since $\Lambda \lesssim \sqrt{F}$ and $m_{\tilde{G}} = \frac{F}{\sqrt{3}M_{\mathrm{Planck}}}$

↓

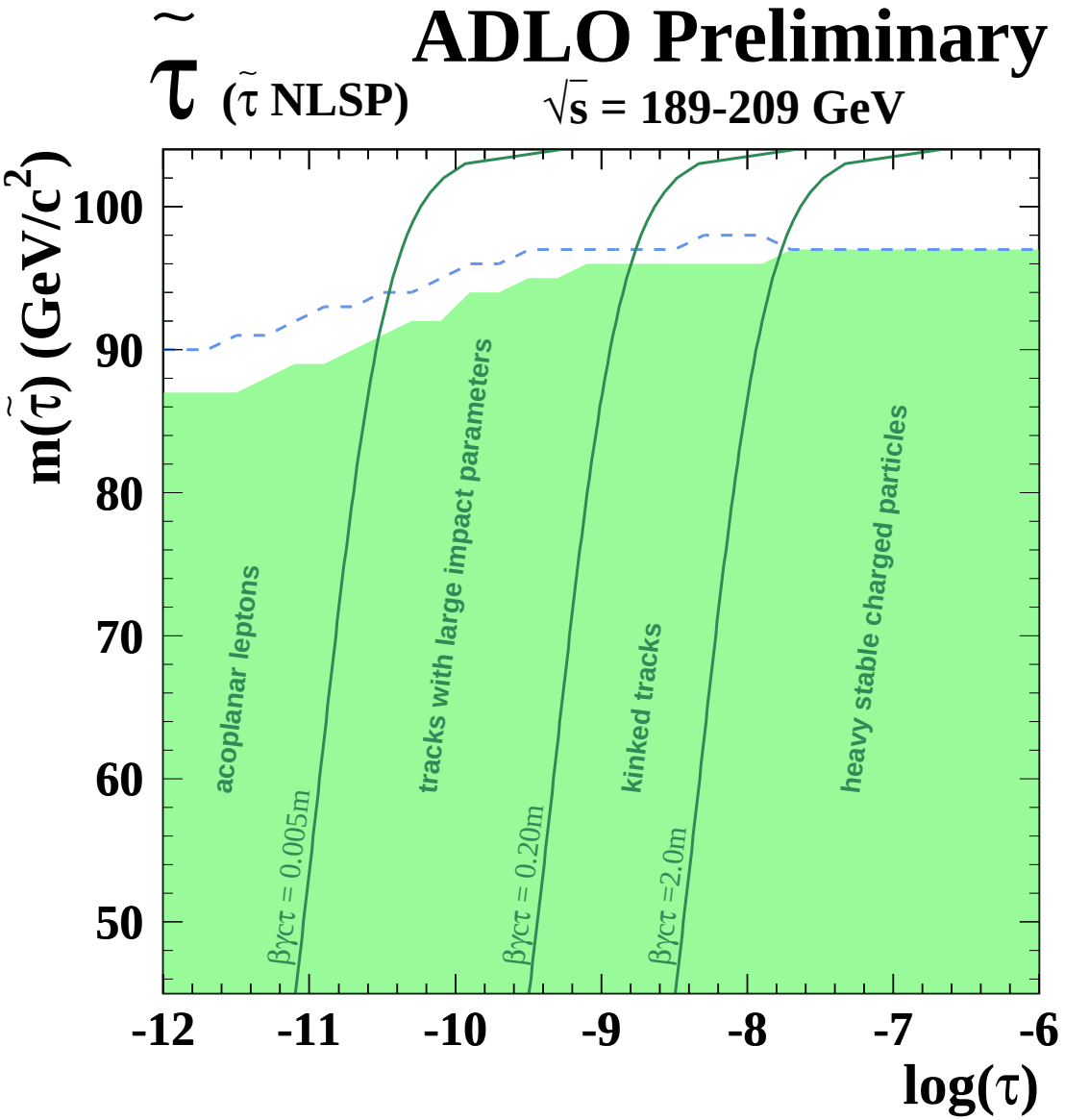
$m_{\tilde{G}} > 0.024\ (0.061)\ \mathrm{eV}/c^2$

Conclusions

- No hint for alternative SUSY at LEP
- Many different topologies have been studied up to the highest energies in GMSB scenarios
- Now covering all lifetimes and most of the parameter space
- (almost) Independent limits on the NLSP mass and the gravitino mass are set
- Still working on final results and combinations
- The quest is now open to Tevatron and LHC: good hunt!

Visit: http://lepsusy.web.cern.ch/lepsusy for updates

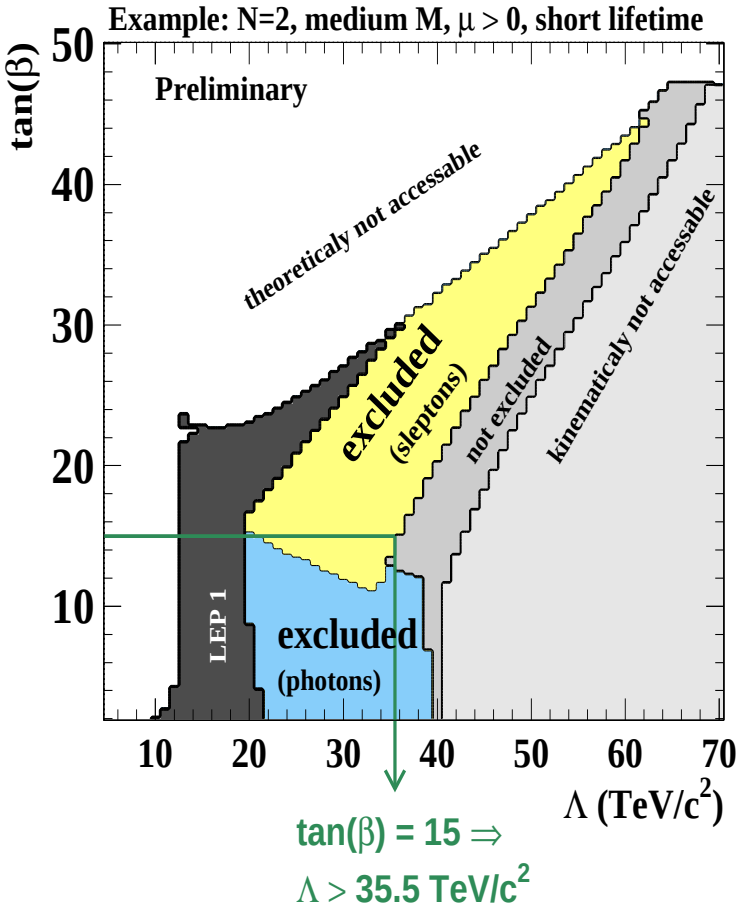
Extra1: Stau limit with searches



Extra2: Tevatron reach and LEP impact

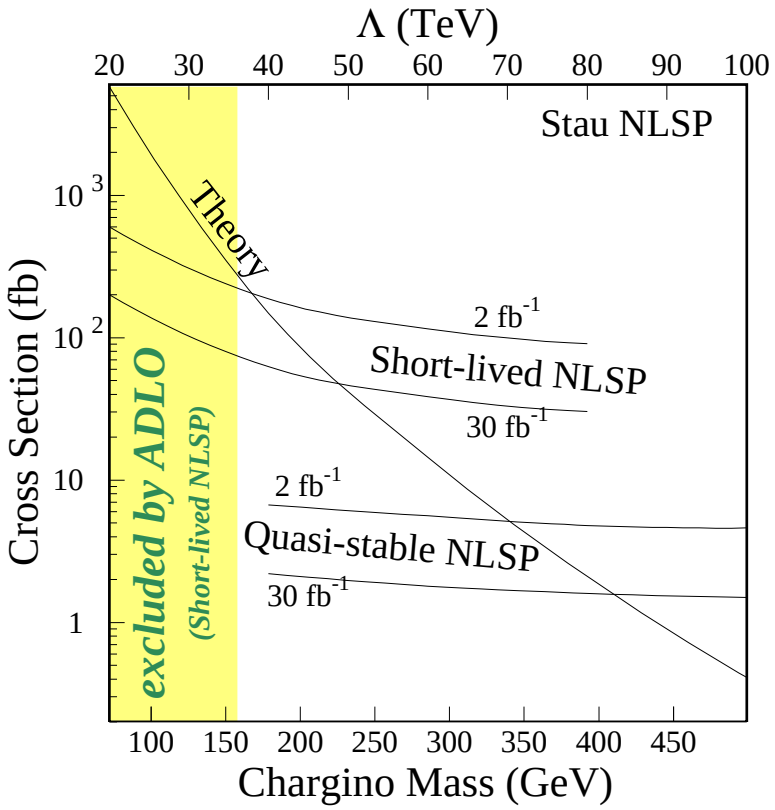
Scan in GMSB parameter space following

Dimopoulos, Thomas, Wells, Nucl. Phys. B488 (1997) 39



J. Quian, hep-ph/9903548 v2:

$N = 2,\ \frac{M}{\Lambda} = 3,\ tan\beta = 15,\ \mu > 0$



5σ discovey reach vs 95%CL exclusion